Clarifying Spill-in/out Effects

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Spill in/out thoughts

- Detector Systematics:

Source of uncertainty		Chooz	Daya Bay (*relative*)		
		(*absolute*)	Baseline	Goal	Goal w/Swapping
# protons		0.8	0.3	0.1	0.006
Detector Efficiency	Energy cuts	0.8	0.2	0.1	0.1
	Position cuts	0.32	0.0	0.0	0.0
	Time cuts	0.4	0.1	0.03	0.03
	H/Gd ratio	1.0	0.1	0.1	0.0
	n multiplicity	0.5	0.05	0.05	0.05
	Trigger	0	0.01	0.01	0.01
	Live time	0	<0.01	<0.01	<0.01
Total detector-related uncertainty		1.7%	0.38%	0.18%	0.12%

- Non-identicalness of detectors will result in uncorrelated spill-in/out effects.
- None of these includes uncertainties from spill-in/out effects
- We should include these in this chart
  - OK, but how large would it be?

Spill in/out thoughts

- Spill-in/out effects for Double Chooz:
  - For single detector, <1% uncertainty from spill-in/out.
    - Where does this come from?
  - Reduces to 0% when using near/far detectors.
  - Single-detector phase is significant part of Double Chooze, so they want to fully understand this effect.

Systematic	% Error
Detector volume	0.2
Scintillator density	0.01
H/C composition	< 0.5
Gd concentration	0.3
Deadtime	0
e+ energy cut	0.1
n loss (spill in/out)	< 1.0
n energy cut	0.1
Time cut	0.4

From M. Worcester (for Double Chooz), NDM09

- Double Chooz has a system to "calibrate" the LS/ GdLS boundary to get a better handle on spill-in/out.
  - Putting neutron sources (Cf-252 or Am-Be) in GdLS near edge and LS
  - Measure effect and compare to MC simulations

Introduction

- Size of spill in/out effect (Basic event distributions)
  - Spill-out: 2.3% - Serves to lower neutron detection efficiency
  - Spill-in: 5.6%
    - antineutrino interactions NOT in target get counted as a target event
- Causes of difference in spill-in/out between ADs:
  - Geometry: shape of IAV
  - Thickness and density of IAV
  - Density of LS and GdLS neutron-catchers and antineutrino targets
    - Antineutrino Targets: protons
    - Neutron catchers: Gd and protons
    - Density differences arise from temperature gradients and production differences

Geometry: shape of IAV

- From DocDB 2106, endcap bulge of 6% (~.35 m!):
  - 1.38% change in number of spill-outs on top compared to bottom
  - This corresponds to 0.02% change in total neutron captures compared to standard geometry.
- Can't imagine that this level of deformation will take place.
  - We will see from measuring target mass during filling if this magnitude of deformation is taking place.
- This effect is likely negligible.

IAV Thickness and Density

- Wei's free proton calculations (DocDB 2464):
  - IAV thickness (volume) tolerance is +/- 5-10%
  - Difference in free proton density between acrylic and LS/GdLS: 10.7%
  - All spill-in: extra IAV thickness converted to LS
    - Change in thickness effects # of spill in from old acrylic region by 1.07%
    - Acrylic only contributes 1.2% of neutron captures
    - Total = 1.2% x 1.07% = **0.013% effect on spill-in**
  - Spill-out: extra IAV thickness converted to GdLS
    - Take away 10% of acrylic spill-ins, 10% x 1.2% = 0.12% less spill-ins
      - However, because of reduced thickness, neutrons from further out in LS would be more likely to reach GdLS and be a spill-in event.
    - Add extra spill-outs, hard to calculate; say 1/2 spill out: 0.12% x 50% / 89.3% (difference in free proton density) = ~0.06% more spill-outs.
      - However, because of increased amount of GdLS at edge of target volume, more neutrons from further in would be more likely to capture in target volume.
    - **Misleading 0.18% effect; definitely lower.**
      - Should we simulate this?

IAV Density

- Acrylic density varies less than 0.1% (DocDB 3533)
  - Results in change of acrylic n-captures by 0.1%
  - 1.2% (acrylic contribution to total n Gd-captures) x 0.1% = .0012%

Density of Protons

- Density effects # of targets in GdLS and LS for neutrino interaction and thus spill in/out effect
  - For example: extra-dense LS means more spill-in events.
- Temperature changes
  - Per AD, temperature is likely to be more or less equal from GdLS to LS
    - Change in density is thus likely to be very small, ~0.07% per 1 K GdLS/LS temp. difference
      - See DocDB 3751, page 8
    - So, 0.07% change in a 5.6% spill-out effect is a net effect of 0.004%; NEGLIGIBLE
- Production differences
  - Spec on density uniformity: LS/GdLS density identical to 1%
    - 4ton test batch: densities different by .2%
  - 1% change in a 5.6% spill-in effect: 0.056% effect
  - relative H/C ratio: couldn’t find this anywhere, I think 0.1%
    - 0.1% change in a 5.6% spill-in effect: 0.0056% effect

Density of Gadolinium

- Differences in H/Gd ratio:

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- Effects the transport of neutrons around GdLS/LS boundary

- Size of effect is unknown, simulations would be required to get an answer.

Summary of Spill-in/out effects:

- Contributors to spill-in/out uncertainty:
  - Geometry: <0.02%
  - IAV thickness: <0.18%, probably more like 0.013%
    - Not entirely sure about this figure; run MC simulations?
  - IAV density: <0.0012%
  - temperature-related proton density: 0.004%
  - production-related proton density: 0.05%
  - GdLS density: unknown
- Total by adding in quadrature: ~0.06%
  - Far from a leading systematic uncertainty, but not quite confident yet in this conclusion.
- Questions:
  - Should we spend time doing simulations to clear up spill in/out ambiguities?
  - Can we do anything with the existing calibration infrastructure to "calibrate" spill-in/out effect for each AD?

[redacted]

Additional:

- While we know the simulated spill in/out effect, how can we measure spill in/out effect in real AD?
    - Double Chooz deploys neutron source in gamma-catcher to check spill-in, and in the target near the gamma-catcher boundary.
    - Can we do the same with our off-axis target ACU and gamma catcher ACU?
- Just use our simulations as a guide?